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IS 8188 (1999): Treatment of Water for Cooling Towers -
Code of Practice [CHD 13: Water Quality for Industrial
Purposes]



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“Knowledge is such a treasure which cannot be stolen”

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IS 8186 : 1999

भारतीय मानक
शीतलन टावरों के लिए जल उपचार – रीति संहिता
(पहला पुनरीक्षण)

Indian Standard
TREATMENT OF WATER FOR COOLING TOWERS —
CODE OF PRACTICE
(*First Revision*)

ICS 13 060

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
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FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Water Quality Sectional Committee had been approved by the Chemical Division Council

Large quantities of water are used for cooling purpose in various industries like power plants, distilleries, oil refineries, chemical plants, steel mills, petrochemical complexes, etc. However, water as received from the source may not be quite fit due to variation in its quality from source to source. Corrosion, scale deposition and fouling invariably pose problems in cooling water system, leading many a times to failures, unscheduled shutdowns and loss of production. In order to overcome any adverse effect it is usually necessary to carry out treatment of the water before it is used for cooling in the plant.

This standard provides a general guideline for selecting suitable treatment schemes of water for industrial cooling system and also suggests for optimum cooling water quality, which should be tried to achieve for efficient operation of the cooling system.

This standard was first published in 1976. Since then the real life data obtained during the implementation of this standard and the comments received from the users of this standard have prompted the Committee to consider the following aspects in revising this standard in order to ensure better evaluation of the performance of cooling system and effective monitoring and maintenance of the same:

- a) biocide efficacy,
- b) selection of corrosion inhibitor,
- c) assessment of corrosion,
- d) interpretation of bio-analysis report, and
- e) guidelines for optimum dosage of inhibitors.

In this revision, the following aspects have been elaborated based on the experience gained during the past and also in view of the technological development taken place:

- a) selection of cooling system,
- b) methods of treatment, and
- c) evaluation and monitoring of the system.

The salient features of water quality for recirculating type cooling system are described in **7.1.3** of this standard.

In the preparation of this standard, useful assistance has been derived from the following publications:

NORDELL (E) Water treatment for industrial and other uses Ed 2, 1961, Reinhold Publishing Corporation, New York

Betz handbook of industrial water conditioning, Ed 6, 1962 Betz Laboratories Inc., Trevese, Penns/Ivania

Primer on cooling water treating, National Association of Corrosion Engineers, USA

Nalco water handbook by Frank N. Kemmer (second edition) — Published by McGraw Hill Book Company

Sheldon D. Strauss — Cooling water treatment for control of scaling, fouling, corrosion

Composition of the Committee responsible for formulation of this standard is given in Annex B.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2-1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

**AMENDMENT NO. 1 JANUARY 2009
TO
IS 8188 : 1999 TREATMENT OF WATER FOR COOLING
TOWERS — CODE OF PRACTICE**

(*First Revision*)

[Page 3, clause 6.3.2.5(a)] — Substitute the following for the existing text

'Dispersants — Suitable chemicals in specified amounts are added as sludge fluidizers, surfactants and wetting agents. These keep particles suspended in the water and prevent deposit formation. Natural dispersants such as lignins and tannins provide good results but these must be used continuously and relatively at high dosages (50 to 200 ppm). However, these provide excellent food for biological organisms which cultivate and create another problem in the system. They also react with chlorine or iron salts. Hence, synthetic polymers most commonly polyacrylates/methacrylates of different molecular weights are used at concentration of 4 to 5 ppm. Dosage level is determined by considering the water characteristics, cycle of concentration, temperature profile on the process side, etc. Lower levels are used in once through cooling systems. Now-a-days, different types of tagged polymers are available which can be monitored on line to determine the optimum dosage level.'

[Page 4, clause 6.3.2.5(d)(v)] — Add the following after (v)'

- 'vi) *Dibromonirilapropionamide (DBNPA)* — This is used in large recirculating and once through cooling tower. DBNPA is the fastest active non-oxidizing biocide and is not persistent. This hydrolyses quickly under both acidic and alkaline conditions and hence increased dosages must be used. It is preferred for its instability in water as it quickly kills bacteria and then degrades to ammonia and bromide ions.
- vii) *Glutaraldehyde* — This versatile molecule is used to control the growth of bacteria, fungi and algae, including sulphate reducing bacteria. Glutaraldehyde is one of the few biocides that contains only carbon, hydrogen and oxygen, thus making it both halogen-free (no AOX issues) and readily biodegradable in the environment. The carbonyl groups of glutaraldehyde cross-link with the amino groups (NH₂) contained within the cell wall of microorganisms, and in effect, prevents the microbe from receiving nutrients or discarding waste products through its cell. Glutaraldehyde is compatible with hydrogen sulfide, and is very effective against anaerobic bacteria. However, glutaraldehyde reacts with ammonia and hence, it is best to avoid using the glutaraldehyde in ammonia leaks situations or in treatment of ammonia chillers'

(CHD 13)

Reprography Unit, BIS, New Delhi, India

Indian Standard

TREATMENT OF WATER FOR COOLING TOWERS

CODE OF PRACTICE

(*First Revision*)

1 SCOPE

This standard deals with the conditions to be aimed at, and the methods of chemical treatment for attaining them for different types of industrial water cooling systems.

2 TYPES OF COOLING WATER SYSTEMS

Three types of cooling water systems are generally in use

- a) **Once Through Cooling Systems** - Feature single pass flow through heat exchange equipment to return to the receiving body and are in extensive use at locations offering large and consistent supplies of water.
- b) **Closed Recirculatory Systems** — In these systems water is completely confined within the system pipes and heat exchangers. The heat absorbed from the plant process is generally dissipated by air cooling. The most familiar examples of this system are automobile radiators and refrigeration units, electric generators and chilled water system, etc.
- c) **Open Recirculating System** — It is most widely used system in power plant chemical, petrochemical, petroleum refining steel, paper mill and all types of processing plants. Here, water is continuously reused as in the closed system, but the system is open to the air in a cooling tower. As a result make-up water must be added continuously to replace the loss in evaporation and the air drift loss.

3 SOURCES OF WATER

Normally, the sources of cooling water are classified into the following three groups.

- a) **Ground Water** — Wells, borewells and springs
- b) **Surface Water** — Lake, pond reservoir, river, canal
- c) **Sea Water** — Including backsea water, Estuarine, Brackish water

4 MATERIAL OF CONSTRUCTION OF COOLING SYSTEM

Generally following materials of construction are used on cooling water side.

- a) **Piping** — Carbon steel, mild steel concrete pipes
- b) **Pumps** — Impellers and body; normally of cast iron
- c) **Coolers and Condensers for**
Fertiliser Oil Refineries — Stainless steel and carbon steel generally admiralty brass or in some cases combination of admiralty brass and carbon steel
Petrochemicals — Combination of 90.10 copper-nickel, admiralty brass, SS carbon steel
LPG — Mainly carbon steel
Acrylic Fibre Plants — Stainless steel, copper-nickel, carbon steel
Chilling and Refrigeration Plants — 90/10 Copper-Nickel, copper/stainless steel (SS)
Air Compressor and Nitrogen Plants — Admiralty brass.
Power Plants — Admiralty brass/aluminium brass/copper-nickel/copper SS and even titanium where sea water is used.
Cooling Tower — RCC construction/wood construction/fibre reinforced plastic (FRP)/polyvinyl chloride (PVC)

5 PURPOSE OF TREATMENT WATER

5.1 Source water to be used for cooling purpose needs to be treated for the following reasons

- a) To remove coarse debris and larger life forms, for example. Vegetation, Fish and rubbish, which may choke the cooling system
- b) To remove fine suspended matter to prevent erosion and to prevent the formation of accumulations of material which would adversely affect heat transfer and possibly induce corrosion. Also, large accumulation of settled out solids can choke cooling system including cooling tower ponds
- c) To remove excess free carbon dioxide (CO₂) and iron/manganese present in water particularly in case of ground water. More CO₂ than equilibrium is aggressive, while less from equilibrium can give rise to calcium carbonate (CaCO₃) scale formation. Similarly, large

amount of iron and manganese can foul the tubes and induce corrosion.

- d) To inhibit the growth of micro-organisms on heat exchange surfaces and also to prevent the growth of shell fish in cooling water, intake culvert, etc, particularly with sea water
- e) To prevent the formation of scale which would affect heat transfer and impede flow of water. Though calcium bicarbonate is by far the most common scale found in cooling water system, attention should also be paid on less commonly found scale like calcium sulphate, calcium phosphate, magnesium silicate, etc.
- f) To remove the corrosive potential of the cooling water due to dissolved oxygen, dissolved or suspended salts, alkaline or acidic water velocity, temperature, microbial growth, etc

5.2 In once through cooling system, since very large quantity of water is required for cooling, the cost of adding expensive treatment chemicals to water that is soon discharged from the system, can be prohibitive. Also, they can contaminate large volumes of receiving water. Hence an economic and effective way of treatment of such water is to be found out.

5.3 In closed recirculating system, cooling water is never lost except through some leaks. The most serious problems these systems exhibit are corrosion and the corrosion products which are not removed but accumulate to foul the system. Hence, extremely high levels of corrosion inhibitor are used to eliminate corrosion. The introduced chemicals also remain with the system and may lose its effectiveness with lapse of time.

5.4 The open recirculating system has the greatest potential for all types of problems of deposit corrosion and microbiological problems in comparison with other cooling systems and therefore, treatment of water is essential.

5.5 In general, treatment might have to take into account other uses of water and restrictions imposed by the local authorities on the quality of water to be discharged into rivers, lakes, etc.

6 METHODS OF TREATMENT

Any of the following methods alone or a combination of them, as appropriate depending upon the site conditions can be used.

6.1 Removal of Coarse Debris

Screens of usually 7.5 cm are used at the water inlet to remove coarse floating debris such as vegetation, rubbish and larger life forms. Debris, as accumulated on the screen, are then removed mechanically at a

regular interval to keep the screen clean and to maintain the usual flow of water.

6.2 Removal of Suspended Matters

Suspended matters like sand, silt, mud and remains of shell, fish, etc, are likely to foul the cooling water tubes, which can be removed by any of the following ways

6.2.1 Travelling Water Screen — Screens of size 0.4 to 0.5 mm are allowed to rotate with powerful motor rolling vertically upside down. While rolling downwards on the other side of the rolling mechanism, it is washed continuously to remove the accumulated dirt on it, the washed dirt is led to drain through a separate channel.

6.2.2 Settling Tanks/Ponds — Water is allowed to pass through the tanks very slowly giving coarser particles of suspended matter sufficient time to settle down. The settled sludge is then removed from the tank at regular intervals through suitable dredging pumps or through suitable dredging arrangement if the tank/pond size is large.

6.2.3 Filtration — Since cooling water carry some suspended matters from the source itself and some suspended matters like dirt, dust, sand, slime, dead algae, etc, are contributors from the cooling system also, filtration in some of the cooling schemes, particularly in open circulating system cooling tower is found a necessity. Water is generally filtered through a pressure filter where suspended particles are retained and the filtered water is used for cooling. Mucous accumulated on the filter beds are then removed through backwash of the filter bed. However, in a large plant, where the volume of cooling water in circuit is very large, provision of side stream filtration is made and a part of cooling water in circuit is continuously filtered to ensure clean water in the system. For this purpose filtration plants have also been designed for auto-backwash of filter bed while in service itself. Sometimes, at the inlet point of pressure filter some coagulant like Alum or poly-electrolyte solution in small amount is also added which help finer suspended matters including the colloidal ones to aggregate and settle down quickly on the filter bed.

6.3 Fouling Control

Fouling is the accumulation of suspended matters on heat exchanger surfaces and the foulants can enter the cooling system both from water and air and also from the function of the system itself as below

- a) *Water* — Mud/silt, Natural organics, dissolved solids, Micro-organisms, coagulants,

flocculant, phosphates, detergents, Sewage, etc

- b) *Air* — Dust, vegetation (organics), Micro-organisms, Microorganisms Gases (Organic), Ammonia, Hydrogen Sulphide, Sulfur dioxide, etc
- c) *System* — Corrosion products, Inhibitor reactants, Process contaminants, wood preservatives, oil, etc. Fouling is caused as cooling systems are operated for longer periods ignoring the cleaning schedule and at higher water temperatures and heat transfer rates

6.3.2 Control Techniques

6.3.2.1 Filters (see 6.2.3)

6.3.2.2 Blow down

Concentration of foulants are not allowed to increase to a certain level. Before it is formed in the system, these are released through discharge of some water and having fresh make up water in the system.

6.3.2.3 On-load cleaning

This technique involves injecting small rubber balls into heat exchanger tubes during operation, wiping the tubes clean as they pass through. Once the system injects the balls in the tubes, they pass through the tubes and are caught on a screen at the end of the passage, to repeat the scouring action on the tube surfaces.

6.3.2.4 Off-load periodic cleaning

For this, plugs or brushes are used for scouring. These are held in plastic holders inserted in the tube ends. The cooling water flow pushes the plugs through the tubes to wipe deposits from the tube surfaces. The cleaning process is repeated by reversing the water flow.

Alternatively, long nylon brushes are employed to clean the tubes one by one manually.

6.3.2.5 Control by chemicals

- a) *Dispersants* — Suitable chemicals in specified amounts are added as sludge fluidisers, surfactants and wetting agents. These keep particles suspended in the water and prevent deposit formation. Natural dispersants such as lignine and tannins provide good results but these must be used continuously and relatively at high dosages (50 to 200 ppm). However, these provide excellent food for biological organisms which cultivate and create another problem in the system. They also react with chlorine or iron salts. Hence, synthetic polymers most commonly poly-

acrylates of different molecular weight are used at concentration of 4 to 5 ppm. Lower levels are however, used in once through cooling systems.

- b) *Sludge fluidisers* — These function in the opposite manner to polyacrylates dispersants, serving to agglomerate fine suspended solids to form much larger non adhering particle that can flow out of the system through blow down. These chemicals comprise generally of polyacrylates and are of very high molecular weight (in the millions). The agglomeration action not only fluidises the foulants mud, slime deposit, silt iron, etc, but also causes the particles to be spread out and kept apart thus giving the impression of 'puffing up' the deposit. For once through cooling system, sludge fluidisers are usually used for a short time (one hour each day at a dosage of 1 ppm or less), whereas in recirculating cooling system and in closed system dosage of 0.2 to 0.5 ppm is generally employed. Other fluidisers comprising of polyamines, polyacrylates and various copolymers having molecular weight in the range of 500 to 5 millions are also used for the purpose.
- c) *Surfactants* — Surfactants and wetting agents are commonly used for oily or gelatinous foulants. They help to disperse oils, greases and biological deposits to be removed with the blow down. Dosage are 10-20 ppm depending on the amount of oily foulant present. When large amount of oil is involved emulsifying chemicals may be used for rapid clean up.
- d) *Biocides* — Biocides give effective protection against Bio-fouling both in micro-fouling of heat exchangers by algae and bacteria and in macro-fouling of inlet and discharge channels by mussels, clams, etc. In cooling tower system, these foulants are more notorious, as temperature and pH of cooling water with warm sunlight and Oxygen and Organic and inorganic salts present as nutrients create very much favourable environment for growth and cultivation of biomass. Chlorine is the most familiar and effective industrial biocide in the form of Hypochlorous acid. This diffuses easily through the cell walls of micro-organism reaching the cytoplasm to produce a chemically stable nitrogen-chlorine bond with the cell proteins. Chlorine also oxidises the active sites on certain co-enzyme sulfhydryl groups that are intermediate steps

in the production of Adenosine triphosphate (ATP) which is essential to microbial respiration. Algae are generally easier to kill than killing bacteria. The dosing of chlorine is done in an intermittent manner so as to maintain 0.2 to 0.5 ppm of residual chlorine in the cooling water after one hour of chlorination. In certain cases low dose continuous chlorination or exomotive chlorination is also practiced.

The optimum pH values of cooling water in which chlorine dosing is best effective, is 6.5 to 7.5. While using chlorine, the chlorine demand has to be met. The presence of reducing agents and nitrogeneous matter including ammonia, demands for stronger doses of chlorine. Certain micro-organisms sometime become immune to the regular dose of chlorine. Hence, under such circumstances 'Stock Chlorination' employing heavy doses of chlorine for few hours are undertaken to kill the micro-organisms. Chlorine alternatives are regularly being searched out with the environmental concern of avoiding residual chlorine in the receiving water body, and also due to its hazardous nature in handling and transportation. In some utilities, where sea water is used for cooling purpose, chlorine is generated on the spot by electrolysis of sea water and thus the hazards of chlorine handling and transportation are solved. Alternative oxidizing chemicals like chlorine dioxide, Bromine chloride, chlorinated bromine, etc., are not cost effective. However, some of non-oxidizing biocides commonly used are as follows:

- i) *Methylene bis-thiocyanate (MBT)* — It is effective in inhibiting algae, fungi and bacteria, most notably the *disulphovibria* species (sulphate reducing bacteria causing severe corrosion in cooling system). This is however, inactivated in systems heavily fouled with dissolved ferric iron and also it hydrolyses above pH 7.5.
- ii) *Organa tin compound* — These are known for their toxicity to algae, moulds and wood rotting organisms. The compounds function best in the alkaline pH range.
- iii) *Quaternary ammonium salts* — These cationic surface active chemicals are generally most effective against algae and bacteria in alkaline pH range. However, these lose their activity in presence of heavy dirt, oil and debris. Also, its overdose produces extensive foaming.
- iv) *Organo sulphur* — These are highly effective against fungi and slime forming bacteria, particularly sulphate reducing bacteria. Where the cooling water is also used in paper and food production, these compounds find wide application.
- v) *Copper salts* — They have been effective in cooling pond algaes when used in the range of 1 to 2 ppm as copper sulphate. However, these are not used now because of environmental problems and also cupric ions plating out on steel to form a cathodic element.

NOTE The effectiveness and the characteristics of some commonly used biocides are given in Table 1

6.4 Scale Control

Scale occurs when soluble salts are precipitated and deposited from cooling water to the heat exchanging surfaces. The rate of formation depends mainly on (i) Temperature, (ii) Alkalinity or Acidity, and (iii) Amount of scale forming material in the water. Calcium carbonate is by far the most common scale found in cooling water systems which normally results from the break down of calcium bicarbonate present in water, and its formation depends upon the total dissolved salts, pH and temperature of the water. Other scale occurrences in cooling water system are as below:

<i>Most Common</i>	<i>Less Frequent</i>
Calcium Carbonate	Iron Oxide
Calcium Sulphate	Zinc Phosphate
Calcium Phosphate	Calcium Fluoride
Magnesium Silicate	Iron Carbonate
Silica	Aluminium Oxide

Actions for preventive measures and leading scale control agents are as follows.

6.4.1 Limiting Cycle of Concentration

In recirculating type of cooling, a definite concentration of scale forming salts are allowed to retain in the system, beyond which salts are likely to precipitate to form scales. For example, the following are the cycles of concentration for calcium bicarbonate.

<i>Concentration of Calcium Bicarbonate in Make Up Water, as CaCO₃ in ppm</i>	<i>Cycle of Concentration (COC) in ppm</i>
100	2.0
150	1.7
200	1.5
250	1.3
300	1.1

Table 1 Effectiveness and Characteristics of Biocides Against Fouling Organisms

[Note under Clause 6.3.2.5 (d)(v)]

Microbiocide	Bacteria				Fungi	Algae	Comments
	Slime-forming		Iron-Depositing	Corrosive			
	Spore formers	Non-spore formers					
Chlorine	+	+++	+++	0	+	+++	Oxidizing, dangerous to handle, corrosion to metals, powder, gas or liquid, loses effectiveness at higher pH
Quarternary ammonium salts	+++	+++	+++	++	+	++	Foams, cationic
Organo-tm plus quarternaries	+++	+++	+++	+++	++	+++	Foams, cationic
Methylene bis-thiocyanate	+++	+++	++	++	+	+	Not effective at pH 7.5. non-ionic
Isothiazolones	+++	+++	++	++	++	+++	Dangerous to handle, loses effectiveness above pH 7.5, non-ionic
Copper sails	+	+	+	0	+	+++	May cause copper plating
Bromine organics	+++	+++	+++	++	0	+	Hydrolyses, must be fed directly from drum
Organo-sulphur	++	+++	++	++	++	0	Toxic effluent, reduces chromate, anionic
Note — 0 indicates non-scaling + indicates scaling tendency							

Hence to attain the above purging of water from the cooling cycle, fresh make up water is required to be taken into the circuit. Similarly, Blowdown of cooling cycle water is required when calcium sulphate and silica values are exceeding 1 250 ppm and 125 ppm, respectively

6.4.2 Softening of Make-up Water

The process removes Calcium and Magnesium either by lime soda softening or by ion-exchange. However, before softening, water is required to be cleaned and filtered. Such softened water of zero to 5 ppm hardness as CaCO_3 is supplied as make up to the recirculating cooling water system, and the chances of precipitation of CaCO_3 scale is minimized provided alkalinity and total dissolved salts of the cooling water do not become very high to affect the scaling index (see Fig 1)

6.4.3 Use of Lime Soda softening is sometimes not preferred, as it gives very high pH water and also sometimes lime portions are carried over to the softened water. Also, it does not remove hardness completely. Ion-exchange softening (Base Exchanger) leaves behind a problem of discharge of waste regenerant (Brine solution)

6.4.3.1 pH adjustment of cooling water

A prediction of calcium carbonate scale formation is done by determining any one of the following, for example, Langelier (saturation) index, Ryznar (stability) index and Puckorius (Modified stability) index and accordingly pH of cooling water is adjusted by dosing acid or alkali as given in Table 2. The

saturation index is then found out as the algebraic difference between the actual measure of pH and the above calculated pH_s

That is

Langelier (Saturation) Index 0 indicates non scaling

$\text{LSI} = \text{pH}_{\text{actual}} - \text{pH}_s$ + indicates scaling tendency

Ryznar (Stability) Index > 6 indicates non-scaling tendency

$\text{RSI} = 2 \text{pH}_s - \text{pH}_{\text{actual}}$ < 6 indicates scaling tendency

Puckorius (Modified Stability) Index do

$\text{PSI} = 2 \text{pH}_s - \text{pH}_{\text{equilibrium}}$ $\text{pH}_{\text{equilibrium}}$ is based on total alkalinity

where

$$\text{pH}_{\text{equilibrium}} = 1.465 \log(\text{total alkalinity})$$

6.4.3.2 Scaling severity keyed to Index are as below

LSI	RSI	Condition
3.0	3.0	Extremely severe scaling
2.0	4.0	Very severe
1.0	5.0	Severe
0.5	5.5	Moderate
0.2	5.8	Slight
0.0	6.0	Stable water (No scaling or tendency to dissolve scale, that is, corrosive tendency)

LSI	RSI	Condition
-0.2	6.5	No scaling, very slight tendency to dissolve scale/corrosive tendency
-0.5	7.0	No scaling, slight tendency to dissolve scale/corrosive tendency
-1.0	8.0	do Moderate tendency
-2.0	9.0	do Strong tendency
-3.0	10.0	do Very strong tendency

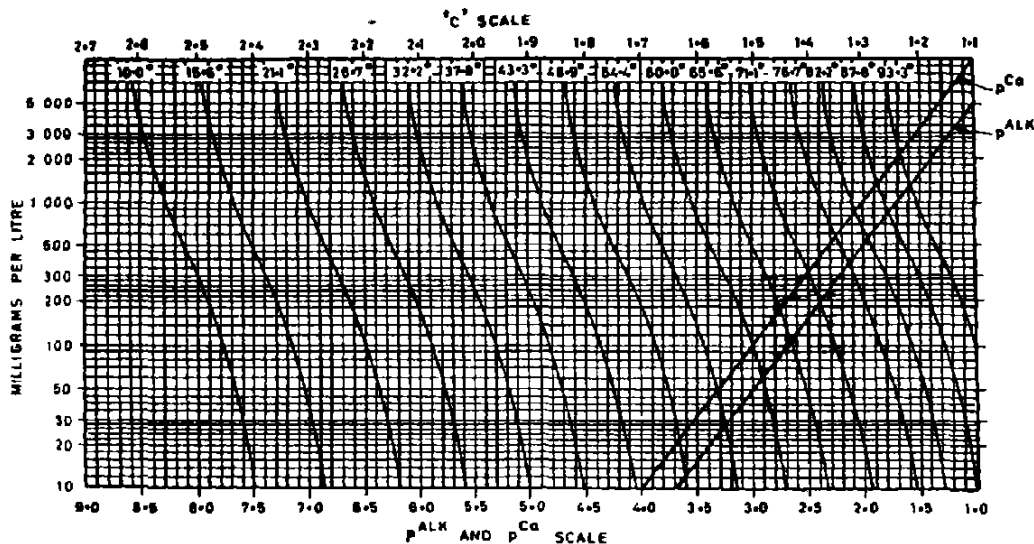
6.4.3.3 Marble test

Besides calculating the saturation pH (pH_s) with the help of charts and tables, there is yet another experimental method known as 'marble test' which gives saturation pH with calcium carbonate

In this method, the actual pH (pH_{actual}) is taken and then pH_s is determined after gently shaking for few minutes 100 ml of the sample with about 10 g of calcium carbonate (reagent quality). Here again, the

saturation index is calculated from the same formula ($pH - pH_s$). In this method, the actual pH and pH_s will be the same if the water is exactly in equilibrium with calcium carbonate. If the water is super-saturated, then on addition of calcium carbonate to such waters, the latter will deposit calcium carbonate till equilibrium is reached. When calcium carbonate separates out from such waters, there is a decrease in alkalinity and consequently the pH also decreases and so the saturation index for such water will be positive which would mean scaling. If the water is undersaturated, then addition of calcium carbonate to such waters will dissolve calcium carbonate till equilibrium is reached. When calcium carbonate is dissolved, there is an increase of alkalinity and consequently the pH also increases and hence the saturation index for such water will be negative which would mean corrosive.

NOTE — The 'marble test' is a quick test for use in the field. It is also useful for supplementing the results of Langelier Index provided both the tests are carried under identical conditions.



To determine

pCa Locate mg/l value for Ca as $CaCO_3$ on the mg/l scale. Proceed horizontally to the left diagonal line down to the pCa scale.

$pALK$ Locate mg/l value for methyl orange alkalinity as $CaCO_3$ on the mg/l scale. Proceed horizontally to the right diagonal line down to the $pALK$ scale.

Total Solids Locate mg/l value for total solids on the mg/l scale. Proceed horizontally to the proper temperature line and up to the $^{\circ}C$ scale.

Example

pH = 7.80
 Temp = $60^{\circ}C$
 Ca hardness = 200 mg/l
 Methyl orange alkalinity = 160 mg/l
 Total solids = 400 mg/l

pCa = 2.70
 $pALK$ = 2.50
 C at $60^{\circ}C$ = 1.56
 sum = pH_s = 6.76
 Actual pH = 7.80
 Difference = +1.04
 = Saturation index

FIG 1 LANGEIER SATURATION INDEX CHART

Table 2 Data for Rapid Calculation of Langelier Index¹⁾
(Calcium Carbonate Saturation Index)
 (Clause 6 4.3.1)

A				C				D			
Total Solids mg/l				Calcium Hardness (as CaCO ₃), mg/l				Methyl Orange Alkalinity (asCaCO ₃), mg/l			
A				C				D			
50	to	300	0 1	10	to	11	0 6	10	to	11	1 0
400	to	1 000	0 2	12	to	13	0 7	12	to	13	1 1
				14	to	17	0.8	14	to	17	1 2
				18	to	22	0.9	18	to	22	1 3
				23	to	27	1 0	23	to	27	1 4
				28	to	34	1.1	28	to	35	1.5
				35	to	43	1.2	36	to	44	1 6
				44	to	55	1 3	45	to	55	1 7
				56	to	69	1 4	56	to	69	1 8
				70	to	87	1 5	70	to	88	1 9
				88	to	110	1 6	89	to	110	2 0
				111	to	138	1 7	111	to	139	2 1
				139	to	174	1 8	140	to	176	2 2
				175	to	220	1 9	177	to	220	2 3
				230	to	270	2 0	230	to	270	2 4
				280	to	340	2 1	280	to	350	2 5
				350	to	430	2 2	360	to	440	2 6
				440	to	550	2 3	450	to	550	2 7
				560	to	690	2 4	560	to	690	2 8
				700	to	870	2 5	700	to	880	2 9
				880	to	1 000	2 6	890	to	1 000	3 0
B											
Temperature, °C											
0	to	1 1	2 6								
2 2	to	5 5	2 5								
6 7	to	8 9	2 4								
10 0	to	13 3	2 3								
14 4	to	16 7	2 2								
17 8	to	21 1	2 1								
22 2	to	26 7	2 0								
27 8	to	31 1	1 9								
32 2	to	36 7	1 8								
37 8	to	43 3	1 7								
44 4	to	50 0	1 6								
51 1	to	55 6	1 5								
56 7	to	63 3	1 4								
64 4	to	71 1	1 3								
72 2	to	81 1	1 2								

¹⁾Based on the Langelier formula, Larson-Buswell residue, temperature adjustment arranged by Nordell

6.4.3.4 To adjust the pH, use of alkali (NaOH) is seldom in use because the pH of recirculating water is generally found on alkaline side. Reduction of pH is however invariably required to bring the desirable scaling index. Sulphuric acid is the preferred choice for this, though Hydrochloric acid is more efficient for the purpose. While use of Sulphuric acid is a costly affair, Hydrochloric acid puts concrete steel reinforcement at the risk of corrosion and makes the boiler more vulnerable to the effect of condenser leakage. Use of Sulphuric acid is also limited to a maximum dose of 600 ppm, otherwise chances of sulphate attack to the concrete reinforcement increases.

6.4.4 Polyphosphate Dosing

This dosing at threshold treatment (usually 2 ppm) is used to distort the crystal lattice in the calcium carbonate and slow down crystallization, which when it does occur, results in a soft sludge rather than a hard scale.

6.4.5 Organo Phosphonates/Various Organic Polymers Dosing

6.4.5.1 While the mechanism of the action of these chemicals almost remains same as stabilizing action

of inorganic polyphosphates, these are far superior to polyphosphates as these keep calcium salts in solution even at quite high pH, high scale mineral concentrations and under severe scaling conditions.

6.4.5.2 The same ability has also been exhibited by some of the recently developed low molecular weight polymers, some of which exhibit excellent control of orthophosphate sludge and there is control of iron and heavy metals by the sequestering property of organophosphonates and polymers. The net result is that cooling water systems can be operated at higher cycles and pH whereby corrosion potential is also substantially reduced. However, the reaction of these chemicals when they find entry to high pressure operating boiler through condenser leak, is not yet known.

6.4.5.3 Various organic polymers are in use, these are usually supplied under proprietary name and often used with polyphosphates and organophosphonates. Two phosphonates are most commonly used for calcium carbonate scale control in recirculating cooling water system.

- AMP (Amino methylene phosphonic acid); and

- b) HEDP (1-Hydroxyethylidene -1, 1-disphosphonic acid).

They behave similarly in chemical reaction but AMP is less stable in the system particularly in presence of chlorine. After loosing its stability, it becomes more aggressive towards scale formation. HEDP is stable at chlorine levels, commonly encountered

6.5 Corrosion Control

6.5.1 Basic types of corrosion occurring in cooling water systems are as below

- a) *General* — General attack is a term that describes the uniform distribution of corrosion over an entire metal surface. The large amounts of iron oxides produced through general attack contribute to severe fouling problems. It is mostly due to aqueous condition
- b) Localised or pitting attack occurs when isolated metal areas are corroded. Pitting is the most serious type of corrosion because all the corrosive action is concentrated in a very small area and can cause metal to perforate in a very short time. This can be due to formations of concentration cells in crevices or in dead areas, underlying deposits and micro biological growth, etc
- c) Galvanic attack occurs when two different metals are in physical contact. In such a case the more active metal corrodes rapidly
- d) Chloride attack occurs when chloride is in high amount and hardness is in less amount. This can lead to de-zincification in brass metal and pitting corrosion in mild steel. High chloride can also cause stress corrosion in stainless steel.

6.5.1.1 The following important characteristics of the cooling water can influence the amount and rate of corrosion that will occur

- i) *Presence of dissolved oxygen* — is essential to the cathodic reaction
- ii) *Dissolved solids* — increase the electrical conductivity and hence the corrosion. Chloride and sulphate are particularly corrosive.
- iii) *Suspended solids* — influence corrosion by eroding or abrading and also through precipitation of deposits, forming localised corrosion cells.
- iv) *Acidity* — promote corrosion by increasing both the dissolution rate of the base metal and the protective oxide film formation on metal surfaces

- v) *Microbial growth* — Forms corrosion cells. Even the byproducts of some organisms are themselves corrosive
- vi) *Water velocity* — Increases corrosion by bringing O₂ to the metal and carrying away corrosion products. Also, erodes metal surfaces for protective film at high velocity. Low velocity causes deposits of suspended matter followed by corrosion
- vii) *Temperature* — Corrosion rate is doubled with every 10°C rise. However, above 70°C temperature has little effect on corrosive rates in cooling water system. But both temperature and activity enhance the corrosive effect of cooling water.
- viii) *Presence of CO₂, NH₃H₂S and Chlorine* — Increase the corrosive potential of the circulating water

6.5.2 Approaches for preventing or minimising corrosion in cooling water system singularly or in combination are as follows.

6.5.2.1 pH adjustment

pH is so adjusted by dosing H₂SO₄ or NaOH that the Langelier index of the cooling water is always slightly on positive side either + 0.1 or maximum + 0.2. Slight deposit of CaCO₃ formed in this way on the metal surface will act as protective layer to minimize further corrosion

6.5.2.2 Effective aeration

The make-up water to the recirculating type cooling system is asserted to remove aggressive CO₂ from equilibrium (CO₂ in equilibrium is generally 0.5 ppm in surface water and saturated with oxygen). This is done either by cascading or forced draught or by furnace aerator. In this way BOD value of water is also reduced and minimum micro-organisms are allowed to enter into the cooling system. Attempt should be made to get make-up water of high quality particularly of BOD values not more than 4 ppm, thus minimizing the entry of dangerous bacteria like sulphate reducing bacteria and iron bacteria which promotes corrosion

6.5.2.3 Effective chlorination [see 6.3.2.5(d)]

This will avoid accumulation and cultivation of micro-organisms causing corrosion

6.5.2.4 Balancing the chloride and hardness

De-zincification has been found to occur with waters having a pH of over 8.2 and having the ratio of chloride to carbonate (temporary) hardness greater than the following.

Chloride (Cl ppm)	Carbonate Hardness (as CaCO ₃ in ppm)
10	10
15	15
20	35
30	90
40	120
60	150
100	180

Hence, either the water is softened or if already softened water is in use, it should be blended suitably. De-zincification also occurs at high pH especially above pH 10. Mild steel surfaces have also been noted to have some pitting corrosion due to chloride attack in presence of CO₂ and O₂, where the chloride and hardness in cooling water system are in balanced form. Hence generally hardness to chloride ratio is tried to be kept not more than 3.

6.5.2.5 Polyphosphate dosing

Polyphosphates which are used as scale reduction in the dosage of 2 ppm, have also marked surface active properties and are useful in reducing corrosion.

6.5.2.6 Ferrous sulphate dosing

If Ferrous sulphate is injected into the cooling water system at the inlet of condenser tubes at a dose of 1 ppm for one hour per day or for 30 minutes in every 12 hours, a protective coating of iron oxides in the condenser tubes is formed, which reduce both erosion and corrosion effects. However, the iron oxide film which builds up gradually has to be removed off and on with acid (EDTA/Oxalic acid), to avoid heat transfer impairment. A very good protective coating of iron oxide with ferrous sulphate dosing is reported to have been achieved in sea water cooled condenser tubes.

6.5.2.7 Cathodic protection

In cooling water system, for corrosion purpose, iron acts as anode of an electrochemical cell, while the copper alloys form the cathode. If a third metal or electrode which is more electro-negative than iron is added to the system and electrically connected to the iron and copper, the new electrode will corrode in preference to the iron. Zinc, Magnesium and Aluminium anodes are used for this purpose and are referred to as sacrificial Anodes. Another method to suppress corrosion on iron is through impressed current cathodic protection, in which an external D.C. potential is applied between the third electrode and the original two electrodes in such a way that the third electrode is now the anode to the whole system. Platinised titanium is generally used for such anode material which in itself is also not corroded or taken into solution.

6.5.2.8 Blow down

To avoid deposition of hardness salts and corrosion due to high dissolved salts in the cooling water, purging of cooling water system is required with replenishment by fresh water.

6.5.2.9 Corrosion inhibitor

Since an electrochemical cell is necessary for corrosion, the most logical preventive approach is to destroy or disrupt the cell. One method involves imposing a non-conducting barrier between the metal and the electrolyte in the form of a thin adherent layer or scale on the metal surface, insulating it from the electrolyte. Chemical so used for the purpose is called corrosion inhibitor which can be anodic, cathodic or general. Both anodic and cathodic inhibitors by which either of the anodic or cathodic surfaces get controlled scaling to stop corrosion on its metal surface, could be dangerous also if insufficient amount of inhibitor is used. Protecting the anodic surfaces using anodic inhibitor, the entire corrosion potential is shifted to unprotected corrosion sites and the result could be severe pitting. In case of low concentration of cathodic inhibitor in use, though there is no pitting, but general attack for corrosion takes place. At this stage, some polymers come to rescue, which serve as general corrosion inhibitor and protect both anodic and cathodic surfaces. Further, it has been proved that a combination of cathodic and anodic corrosion inhibitors give best protection at economical use levels. This is called synergetic effect. Though chromate is the oldest and the best known corrosion inhibitor available even today, but because of its high toxicity to aquatic life, cloth staining property and suspected carcinogenic effect on human body, restrictions have been imposed by the environmental authorities on its discharge to water bodies. Hence, non-chromate based corrosion inhibitor combinations are generally in use, usually at the dosage of 50-20 ppm typical of which are as follows:

Zinc	Polyphosphate
Zinc	Organaphosphonate
Zinc	Phosphonate-Polymer
Zinc	Polyphosphate-Silicate
Polyphosphate	Silicate
Polyphosphate	Polymer
Phosphonate	Molybdate
Polysilicate	Molybdate
Zinc	Tannin-Lignin

While giving up the chromate based treatment, molybdate based treatments have found recent use with considerable success. They often contain copper corrosion inhibitors and occasionally nitrites along with

alkali buffering agents to maintain pH above 8.0. The molybdate is carried at levels of 100-200 ppm as MoO₄. For once through cooling system the dosage as recommended is 10-20 ppm. This treatment is not toxic, is environmentally cooptable and does not contribute to biological growth in the cooling water system.

Using copper corrosion inhibitor in a combination is essential because even a minute quantity of copper in water (0.1 ppm) can plate out on Aluminium or mild steel causing severe pitting. There should be minimum use of nitrite as it provides a nutrient supply for biomass present in water. Similar care should be taken while using polyphosphate which can give sludge to form deposits. Zinc at high pH level greater than 8.0 can contribute to fouling if the dosage concentration is above 0.5 ppm. Also, polysilicates should not be used if cooling water contains more than 10 ppm of natural silica. Molybdate is best effective at pH levels above 7.5, but is adversely affected by dissolved solids exceeding 5 000 ppm.

Organic based treatments have been used with some success, although less corrosion protection is obtained than with inorganic inhibitors. These treatments make use of specially polymers, lignine phosphonates and copper corrosion inhibitors. More recently, Mercaptobenzothiazole (MBT) at the dosage of 10 ppm, Benzotriazole (BZT) at 1 ppm dose and tolytriazole (TT) again at 1 ppm dose, are in use with good performance either used alone or in combination. These inhibitors work by forming a very tenacious protective film on copper alloys.

Most of the inhibitors as mentioned above are temperature sensitive. Hence, before use, its sensitivity should be assessed, otherwise, if degraded with temperature, it can severely foul the cooling system.

All corrosion inhibitors at 2-4 times their normal dosage are applied over the first few days after pretreatment/cleaning of metal surfaces. This ensures formation of a durable passivating film rapidly. The pretreatment is also carried out on any system upsets like pH excursions, corrosive contaminants and prolonged low inhibitor levels.

NOTES

1 Criteria for selection of corrosion inhibitors for some selected metals and alloys are given in Table 3

2 Guidelines for assessment of corrosion is given in Table 4 indicating the corrosion rates of certain commonly used metals in water cooling systems

7 MONITORING AND EVALUATION OF TREATMENT PROGRAMME

7.1 Monitoring

7.1.1 The success of any treatment programme depends on maintaining the various parameters within limits. The parameters to be monitored continuously and during every shift are as follows

<i>Continuous</i>	<i>Every Shift</i>
i) pH	i) Residual chlorine
ii) Water level in sump	ii) Langelier Index
iii) Blow down rate	
iv) Make-up water rate	
v) Temperature	

7.1.2 The complete analysis of circulating water and make-up water should be carried out daily and should include-

- i) pH
- ii) Alkalinity

Table 3 Criteria for Corrosion-Inhibitor Choice for Selected Metals

(Note 1 under Clause 6.5.2.9)

Inhibitor	Metal			Limitations			Reducing Conditions ¹⁾	
	Steel	Copper	Aluminium	Calcium ppm	pH	Total Dissolved Solids, ppm	H ₂ S	SO ₂ and Hydrocarbons
Chromate	E	E	E	0 - 1 200	5.5 - 10.0	0 - 20 000	No	No
Polyphosphate	E	Attacks	Attacks	100 - 600	5.5 - 7.5	0 - 20 000	Yes	Yes
Zinc	G	None	None	0 - 1 200	6.5 - 7.0	0 - 5 000	No	Yes
Polysilicate	E	E	E	0 - 1 200	7.5 - 10.0	0 - 5 000	Yes	Yes
Molybdate	G	Fair	Fair	0 - 1 200	7.5 - 10.0	0 - 5 000	No	Yes
Copper inhibitor ²⁾	Fair	E	G	0 - 1 200	6.0 - 10.0	0 - 20 000	Yes	Yes

¹⁾ Indicates treatment suitability under specified condition

²⁾ TT or BZT

E = Excellent

G = Good

Table 4 Guidelines for Assessing Corrosion¹⁾
(Note 2 under Clause 6.5.2.9)

Model	Corrosion Rate, mils/yr	Comments
Carbon steel	0-2	Excellent corrosion resistance
	2-3	Generally acceptable for all systems
	3-5	Fair corrosion resistance acceptable with iron fouling-control program
	5-10	Unacceptable corrosion resistance. Migratory corrosion products may cause severe iron fouling.
Admiralty brass	0-0.2	Generally safe for heat-exchanger tubing and mild-steel equipment
	0.2-0.5	High corrosion rate may enhance corrosion of mild steel
	0.5	Unacceptably high rate for long term, significantly affects mild-steel corrosion
Stainless steel	0-1	Acceptable
	1	Unacceptable corrosion resistance

NOTE To convert mils per year (mpy) to mm per year (mmpy) multiply by 39.4 and to convert mmpy to mg/dm²/day multiply by 2.16

¹⁾ Included rules apply to general system corrosion

- iii) Conductivity
- IV) Turbidity
- v) Calcium and Magnesium Hardness
- vi) Chlorides
- vii) Silica
- viii) Iron
- IX) Ammonia and Nitrates
- x) Any frequent pollutant
- xi) Treatment chemicals

NOTES

- 1 Methods of tests are given in relevant Parts of IS 3025
- 2 Sampling point should be in the return heads
- 3 Feeding of treatment chemicals and acids, etc. should be as per requirements.

7.1.3 The following are the guidelines for maintaining the quality of recirculating type of cooling water for trouble free operation. However, if there is practical difficulty in achieving the same because of too much variation in the quality of the source water itself, attempts should be made either to treat the source water suitably or to take help of suitable treatment chemicals for anti-scalants/anti-foulants and anti-corrosive materials or a combination of all these. The limits as guided for pH, Residual chlorine and Langelier Index are applicable to once through cooling system also

pH	To suit Langelier Index around +0.2
Turbidity	Not greater than 50 NTU
Residual chlorine	0.2 - 0.5 ppm
Total hardness	Not greater than 250 ppm as CaCO ₃

Temporary hardness	Not greater than 200 ppm as CaCO ₃
Chloride . Hardness	Approximately 1.3
Iron + Manganese	Not greater than 0.5 ppm
KMnO ₄ No. (MgO ₂ Absorbed)	Not greater than 2 ppm
C.O.D.	Not greater than 4 ppm
Total dissolved Salts	Not greater than 500 ppm
Carbon dioxide	Consistent with Equilibrium
Sulphate as SO ₄	Not greater than 600 ppm
Silica as SiO ₂	Not greater than 75 ppm

7.2 Evaluation

7.2.1 The treatment programme should be regularly evaluated for

- a) *Corrosion control* - It is done by reassessing corrosion rate normally by corrosion meter which takes into account the corrosion rate due to electrochemical corrosion, but does not take into account the corrosion due to micro organisms while the Coupon tests indicate both. Corrosion coupons are installed in the return header as given in Annex A and are exposed for a minimum period of 30 days. After that, average corrosion for the period is noted. Coupon material should be as close in composition to the metal in the system and the mount along with nut and bolt should be of laminated phenol formaldehyde resin or similar plastic rods. The exposed area of the coupon generally ranges from 1.300 to 2.600 mm².
- b) *Scale and fouling control* — Exact extent of scaling and fouling is difficult to measure. However, assessment may be made indirectly to heat transfer data and periodic inspection of the exchanger which can be isolated for opening without disturbing plant operation.
- c) *Microbiological control* — Regular Microbiological analysis of the circulating water before and after dosing of biocide should be carried out. Normally percent kill of above 80 percent indicates good biocidal effectiveness. Regular inspection of the cooling tower especially louvers and deck for algae and fungus growth will also help in evaluating biocide effectiveness. A typical guideline for interpretation of bio-analysis report is given in Table 5.

Table 5 Significance of Observed Biological Count
(Clause 7.2.1)

Count Range	Inference
0-10 000	Essentially sterile
10 000-5 00 000	System under control
5 00 000-1 million	System may be under control but should be monitored
10 00 000 - 10 million	System out of control — requires biocide
Over 10 million	Serious fouling problems may be occurring — Immediate biocide additive required

NOTE — Typical guidelines for systems that have bio-analysis

7.2.2 It is not possible to simulate all above conditions in the evaluation methods. The inspection of heat exchangers during annual turn around, therefore, gives best indication about the effectiveness of the overall treatment programme. Water formed deposits, if any must be analysed thoroughly. The extent of deposit and its analysis serve as a guide for deciding any improvement in treatment programme, if required.

7.3 System Upsets and Corrective Measures

7.3.1 The cooling water during its circulation is exposed to various conditions arising from the system itself or from the environment. If the exact cause of the upset conditions are diagnosed with corrective steps taken at an early date, the system can be saved from disastrous effects. The normally encountered upset conditions in a cooling water system are as follows.

7.3.1.1 Low pH

This could be due to excess feed of acid/chlorine, ingress of acidic contaminants like CO₂, SO₂ and H₂S and development of acid forming bacteria (Nitrifying bacteria and Sulphate reducing bacteria).

If the low pH is identified due to excess acid feed, the same should be stopped and pH should be monitored hourly, till normal. However during low pH period, concentration of corrosion inhibitor should be increased by 25-30 percent and maintained at this level for 48 hours after regaining the pH.

If the LOW/pH is due to acidic contaminants, the action to be taken is same as above. In case the problem occurs too frequently, it is advisable to operate the system at lower cycles of concentration or stop the exchanger, if the problem persists. This generally happens in a chemical plant where acidic gases are cooled and leak through the tubes in the circulating water.

If the low pH is due to development of acid forming bacteria, the following actions should be taken

- Close blow down.
- Give shock dose of a specific and non-oxidizing biocide, effective for sulphur reducing/nitrifying bacteria.
- Allow the water to circulate for 8-12 hours without blow down.
- Start maximum blow down and continue the same till pH normalises

NOTE — In case the pH drops below 6.0, it is necessary to repassivate the system after normalising the pH. Iron fouling is maximum in this case.

7.3.1.2 High pH

This could be due to improper acid feed, increase in make-up water alkalinity, operation on high cycle of concentration, ingress of ammonia or any alkaline contaminant (mostly in ammonia/chemical plant).

The corrective steps to be taken are to increase the acid feed rate, decrease cycle of concentration and remove leakage of ammonia from the plant.

In case the pH goes above 8.5, the scaling tendency will substantially increase and hence it is necessary to increase the concentration of dispersants/anti-scalants. If high pH persists for a longer time, microbial growth will increase, as high pH is favourable for their growth and chlorine is less effective at high pH. In such cases, it is advisable to give shock dose of non-oxidizing biocide.

7.3.1.3 Ingress of hydrocarbons, oil, methanol, etc

The exact source can be found by analysing either total carbon or chemical oxygen demand using potassium dichromate in the inlet and outlet water of exchangers and action taken accordingly.

The hydrocarbons serve as nutrient for the micro-organisms. In addition, oil acts as a binding medium for the suspending solids and increases fouling of heat transfer surface. Hence, in such cases it is advisable to dose surface active agent like Dioctyl sulfosuccinate at about 10 ppm and flush the system after 12-16 hours of circulation, till foaming subsides completely and oil in circulating water is not traceable. After this it is advisable to give shock dose of non-oxidizing biocide. In case of methanol and other hydrocarbons, immediate shock dosing of non-oxidizing biocide can be given with circulation for 8 hours followed by heavy blow down to flush the methanol/hydrocarbon out of the system.

7.3.1.4 Low inhibitor concentration

This could be due to improper feed of chemicals, degraded chemicals, excessive blow down followed by fresh make up, presence of adsorbent matter in circulating water and high temperature. Ideal dosage

of inhibitors *vis-a-vis* the time taken for film formation is given in Table 6.

Table 6 Guidelines for Film Formation and Subsequent Maintenance

Inhibitor	Dosage, ppm		Film-Formation Time, Days
	Initial	Maintenance	
Chromate	30-50	5-20	3-4
Polyphosphate	40-60	10-30	5-6
Zinc	10-20	3-5	5-6
Polysilicate	40-50	10-20	10-12
Molybdate	40-60	5-20	10-12

Insufficient concentration of treatment chemicals give rise to increased scaling, fouling and corrosion as the case may be. Hence identification of the cause with subsequent remedial measures taken is necessary. In case the drop in concentration is only for sometime, it

should be made up by slug feeding of treatment chemicals. If it is for longer time, acid cleaning and passivation of the system may be necessary.

Adsorbent matter like fly ash and carbon absorb organo-phosphonate which will reduce its concentration in circulating water. Presence of organic phosphate, generally present in the sludge from backwash of side stream filters (if installed) indicate ingress of such type of adsorbent matter.

7.3.1.5 High temperature

High temperature may be due to under design of heat exchanger, less flow rate of cooling water and also due to high dissolved salts. Hence, attempt should be made to identify the cause and take suitable action. High dissolved salts can be brought down by allowing less cycle of concentration.

ANNEX A

(Clause 7.2.1)

EVALUATION OF CORROSION RATES IN COOLING SYSTEM

A-0 Evaluation of corrosion rates in cooling systems to determine the inhibitor's effectiveness may be done by one of the following three methods:

- Metal coupons method,
- Resistance probe method, and
- Test exchanger method.

A-1 METAL COUPONS METHOD

Corrosivity measurements in recirculating cooling water can be done by the use of standard coupons. This method does not give precise values of the corrosion to be expected on the metal surfaces in the system nor does it give an indication of the effect on heat transfer through the metal. It, however, provides values of corrosion rates of the metal which is useful for comparative purposes. Examination of metal coupons can also give an indication of pitting tendencies and scale deposition.

A-1.2 Metal Coupons

Convenient dimensions of metal coupons or strip testers are in the range from 9.5 to 13 mm wide and from 75 to 100 mm long, 0.8 to 1.6 mm thick, with the exposed area ranging from 1 300 to 2 600 mm². Steel specimen should be as close in composition to

the metal in the system as possible. However, if the composition of the metal of system is unknown or varies, the specimens should be prepared from low carbon cold-rolled steel or other metallic specimens can be used as required to match the characteristics of the system which is being studied.

A-1.3 The specimen mount should be a 150 mm long laminated phenol formaldehyde resin or similar plashes rod. This rod may be inserted in a pipe plug either by means of a drive fit or by means of a threaded hole in the plug. The end of the plastics rod should be flattened on one side to take the specimen as shown in Fig. 2. The specimen is secured by a nut and bolt of the same material as the metal coupon to prevent galvanic corrosion. The assembly should be sufficiently steady so that the strip will be held firmly at the centre of the stream of water through the pipe and will not touch the pipe. The plastic rod should be long enough so that the specimen is out of the turbulence in the tee and into the flow of water in the pipe.

A-1.4 Specimen Holder Assembly

An assembly for holding a group of coupons in the water stream under essentially identical conditions is shown in Fig. 3. The assembly consists of a back and forth

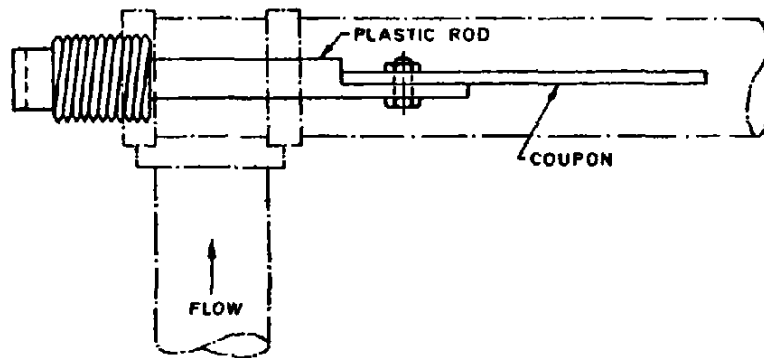


FIG 2 DETAILED DIAGRAM FOR PLACEMENT OF SPECIMEN

arrangement of pipe nipples and tees of proper size to receive the specimens which are to be placed in the pipe. The size of pipe should be large enough to give at least 6 mm of free space on each side of the specimen. The specimen holder assembly should be connected in such a way that the water will flow upward through it, so that the pipe will be completely full of water at all times. For measurement of the corrosivity of the water at the points of highest temperature in the circulating system the specimen holders should be located at the exit of high temperature heat exchangers. A measurement of the average corrosivity of the water may be obtained by locating the specimen holder at return header to the cooling towers.

A-1.5 Preparation of Coupons

Specimen coupons may be cut to size from sheet metal by shearing or cut from a strip of proper width. The hole to hold the specimen in place on the plastic holder should be drilled near one end of the coupon. This hole should be of suitable size to take the bolt and nut which is to hold the coupon in place. Numbers or letters for identification of the coupon should then be stamped on the metal, preferably between the hole and the end, and the specimen degreased and highly polished.

A-1.6 Cleaning of New Coupons

The following coupon cleaning procedures are recommended for use which are accepted to be the simplest for use in the field.

A-1.6.1 For aluminium and copper alloy coupons, sand blast with clean dry sand of size 250 to 300 microns to grey metal. Avoid handling with fingers after sand blasting. Wipe carefully with a clean lint-free cloth.

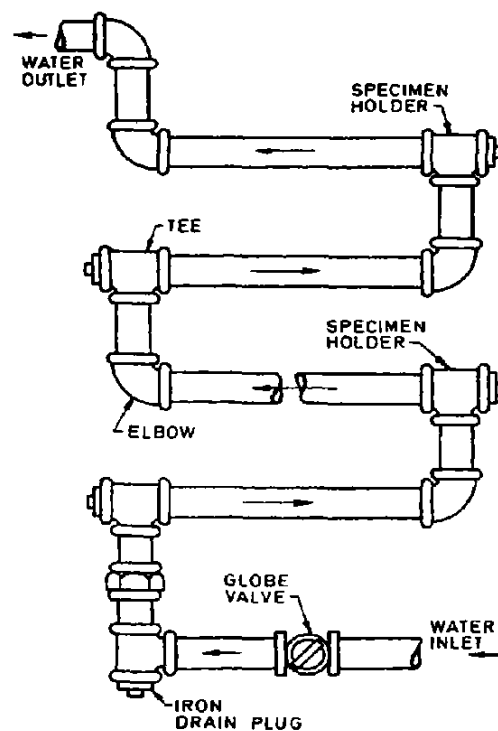


FIG 3 ASSEMBLY FOR HOLDING GROUP OF SPECIMENS

until no more loose material is removed, using hand gloves. Dry in a desiccator for 24 hours.

A-1.6.2 Immerse in 15 percent hydrochloric acid at room temperature for 30 minutes. Rinse in distilled water, dip in 5 percent sodium carbonate solution and rinse with distilled water. Avoid handling with fingers after the acid etch. Wipe thoroughly with a clean lint-free cloth until no more loose material comes off on the cloth. Dip in isopropanol, dry, allow to stand in a desiccator for 24 hours (*see Note*).

NOTE — If a desiccator is not available the specimen can be stored in a metal can with light-fitting lid together with a bag containing dehydrated silica gel.

A-1.7 Installation of Coupon

A-1.7.1 The metal coupons, prepared as described in **A-1.5** and **A-1.6** are weighed to the nearest tenth of a milligram and are then ready for insertion in the tooling water system. They should be mounted on the plastic rods and screwed into the specimen holder assembly as shown in Fig. 2. The water should then be turned on through the specimen support assembly and the flow rate adjusted to give a flow past the specimens of between 1 and 1.5 m/s. The ideal flow would be that used in the actual system under test. In 25 mm dia pipe, a water velocity of 1.1 m/s, corresponds to about 30 l/min. In 20 mm dia pipe, the same linear flow rate is given by about 18 l/min. For usual comparative results, the flow rates shall be checked daily in order to assure that they are being maintained constant.

A-1.7.2 Minimum duration of these tests is 30 days. Test can be extended with the use of multiple coupons for a longer period of time (90 days). It is recommended that always duplicate coupons should be used for such study.

A-1.8 Handling of Coupons After Test

A-1.8.1 At the end of the standard testing time, remove and examine the specimen for the appearance of tuberculation, pitting, deposits and so forth. Record such observations carefully. Remove the deposits on the coupons and analyze to see whether the deposits are due to corrosion or due to scaling.

A-1.8.2 Cleaning of Specimen Coupons

These cleaning procedures are typical of many which have been successfully used. Other cleaning methods may be used, but it is necessary that whatever procedure is used for cleaning the coupons, should also be applied to a fresh unused coupon in order to obtain a figure representing the loss due to the cleaning procedure. This figure is then subtracted from the mass loss of the coupon, and the remainder is assumed

to be the mass loss due to corrosion.

- a) *Steel coupons* — Remove the loose material by brushing with a soft brush under a stream of tap water. If oily deposits are present, degrease the coupons. Suspend the coupons in a full strength solution of inhibited hydrochloric acid at room temperature for 15 s, rinse in water, then in isopropanol, wipe dry with a clean lint-free cloth and place in a desiccator.

NOTE — Inhibited hydrochloric acid may be prepared by dissolving two parts of antimonous oxide (Sb_2O_3) and 5 parts of stannous chloride crystals in 100 parts of concentrated hydrochloric acid.

- b) *Copper alloy coupons* — Follow the procedure given in **A-1.8.2(a)** for cleaning copper alloy coupons.
- c) *Aluminium alloy coupons* — Clean the aluminium alloy coupons by immersing them in a distilled water solution containing 3 percent chromic acid and 5 percent phosphoric acid at 70 to 77°C for 5 minutes. Store the coupons in a desiccator for at least 2 hours before weighing them to the nearest tenth of a milligram.

A-1.9 Description of Local Corrosion and Pitting

Observe the cleaned coupons for localized attack or pitting. If no pitting is evident, describe the appearance as 'no local attack', 'etch', 'even local attack', 'uneven local attack', 'heavy local attack', and express the area of local attack as percentage of the area exposed. Where pitting is present, determine and report the frequency of pitting in terms of pits per square centimetre. Determine the severity of pitting with a feeler gauge or a microscope in terms of maximum pit depth in mm (or mils).

A-1.10 Calculation of Corrosion Rates

A-1.10.1 Calculate the corrosion rates, as an average penetration in mm per year based on the mass loss by the following equation:

$$\text{Penetration} = \frac{365 \times M}{d \times a \times t}$$

where

- M = mass loss in mg,
- d = specific gravity of the metal in terms of g/cm^3 ,
- a = exposed area of coupon in mm^2 , and
- t = time in days.

NOTE — To convert mm per year to mils per year multiply by 39.4 and to convert mm per year to $\text{mg/dm}^2/\text{day}$ multiply by 216.

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A-1.10.2 Calculate the pitting rate using the following equation

$$PR = \frac{\text{Max pit depth} \times 365}{t}$$

where

PR = pitting rate in mm per year (or mpy), and
 t = duration of test in days

Maximum pit depth is measured either in mm (or mils)

A-1.10.3 *Reporting of Results*

The reporting of results of the various measurements should contain the following information

- a) Name of company involved,
- h) Identification of the cooling system,
- c) Identification of the coupon,
- d) Nature of the metal,
- e) Duration of test,
- f) Temperature of water,
- g) Size of pipe,
- h) Flow rate of water,
- j) Mass loss of coupon,
- k) Average penetration either in mm per year or in mils,

- m) Frequency of pitting as pits/mm²,
- n) Severity of pitting as maximum pit depth in mm or in mils, and
- p) Pitting rate either in mm per year or in mpy

A-1.10.3.1 In addition, the appearance of the specimen coupons before and after cleaning should be indicated

A-1.11 Resistance Probe Method

Corrosion rates can be evaluated by the use of resistance probe method. This method has got distinct advantage over the coupon method as it can give instantaneous corrosion rates which can be recorded if desired or used to activate the feed controls

A-1.12 Test Exchanger Method

Corrosion rates can be practically demonstrated in a cooling system by the use of test exchanger method. The test exchanger, besides providing excellent reproduction of field conditions with regard to heat transfer surfaces, velocity effects in tubes, etc., can be used to monitor the corrosivity and scaling tendencies of the system in which it is attached. This is accomplished by the periodic pulling of tubes for corrosion examination and the measurement of pressure drops and steam consumption for fouling tendencies

ANNEX B*(Foreword)***COMMITTEE COMPOSITION****Water Quality Sectional Committee, CHD 013***Chairman*

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